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ASSESSMENT OF A THERMOELECTRIC VEST THROUGH PHYSICAL AND MENTAL PERFORMANCE

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14. ABSTRACT
This study evaluated the efficacy of a thermoelectric (TE) cooling vest developed by AFRL/RX incorporating P-N junction elements. This vest is designed for military personnel that work in hot environments (above 87°F) and was designed to decrease core body temperature and increase vigilance. A series of tests were completed using eleven subjects. Efficacy of the vest was determined by running baseline maximal oxygen uptake (VO_{2max}) on each subject and designing a subject-specific submaximal test with a vigilance task. Each subject completed a total of four submaximal tests wearing the vest 'on' twice and 'off' twice. Analysis of both the core body temperature and the vigilance of the subjects did not find a significant statistical difference of the vest 'on' versus 'off' or vest*time interaction. There was a significant effect of time on core body temperature, which is to be expected due to increased physical workload over time regardless of the vest.

15. SUBJECT TERMS
Thermoelectric, cooling vest, TE, vest, maximal O2, VO2 max, vigilance

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PREFACE

The laboratory tests and data analysis described in this report were accomplished by the Applied Neuroscience Branch, Human Effectiveness Directorate of the Air Force Research Laboratory (711 HPW/RHCP) at Wright-Patterson Air Force Base, Ohio. The test facility for this equipment evaluation was the Human Performance Laboratory (HPL) in Building 840 at Wright-Patterson AFB. Funding was provided by the Air Force Research Lab, cross-directorate Thermal Strategic Technology Team (Thermal STT), led by the Materials and Manufacturing Directorate (AFRL/RX). Engineering support was provided by Infoscitex under contract FA8650-09-D-6949. This study was approved by the Air Force Wright Site Institutional Review Board (IRB) under Protocol F-WR-2010-0186-H.

SUMMARY

This study evaluated the efficacy of a thermoelectric (TE) cooling vest developed by AFRL/RX incorporating Peltier elements. This vest is designed for military personnel that work in hot environments (above 87°F) and was designed to decrease core body temperature and increase vigilance. A series of tests were completed using eleven subjects. Efficacy of the vest was determined by running baseline maximal oxygen uptake (VO_{2max}) on each subject and designing a subject-specific submaximal test with a vigilance task. Each subject completed a total of four submaximal tests wearing the vest ‘on’ twice and ‘off’ twice.

Analysis of both the core body temperature and the vigilance of the subjects did not find a significant statistical difference of the vest ‘on’ versus ‘off’ or vest*time interaction. There was a significant effect of time on core body temperature, which is to be expected due to increased physical workload over time regardless of the vest.

1.0 INTRODUCTION

1.1 Background

Airmen consistently work in operational environments that create significant thermal burdens for the operators of modern military aircraft. Operations in hot and humid environments, in-flight heat from avionics, radiant heating through the canopy, and aerodynamic heating, combined with layers of aircrew life support equipment, can overcome the body's normal mechanisms for heat dissipation within aircraft. Outside of the aircraft, Airmen work on hot and humid flight lines and in other hot spaces.

Hyperthermia can become an issue for Airmen, especially when working in hot environments such as Iraq and Afghanistan. The primary mechanism of heat dissipation in humans performing physical exertion in hot environments is dependent on the redistribution of blood to the skin where heat from the body's core can be transferred to the external environment. The effectiveness of the blood redistribution mechanism, as well as evaporative heat loss through sweating, can be lessened by impermeable materials such as the pneumatic bladder of anti-G suits and chest counterpressure garments, causing the core body temperature to rise. Excessive thermal heat stress has been shown to degrade mental and physical potential and can cause fatalities. Though the human body is able to tolerate extended exposure to heat stress, heat stress accompanied with wearing protective clothing, operating certain combat vehicles, and working in engine or boiler rooms can prove problematic especially during assignments that require intense physical activity (TB MED 507/AFPAM 48-152 (I)). In excessive heat, duty performance slightly decreases after 30 minutes and noticeably decreases after 2 to 3 hours (TB MED 507/AFPAM 48-152(I)). Hyperthermia above 39°C (102.2° F) can cause severe brain injury (Takino 1991). Hyperthermia, like hypothermia, is accompanied with increased acidosis and worsening coagulopathy (bleeding disorder involving the body's blood clotting process) (Hermstad 2010).

The introduction of a thermoelectric (TE) vest into the operational environments could provide a way to reduce the thermal heat stress on Airmen. Providing cooling directly to the Airmen could reduce their core body temperature and increase their mental and physical potential. This could be accomplished by deploying 24V DC powered solid state cooling systems that feeds cool air through a hose to the vest. These solid state heat pumps operate using the Peltier effect (also known as thermoelectric heating/cooling).

An Air Force Research Laboratory (AFRL) cross-directorate Strategic Technology Team (STT), led by AFRL/RX, was established to research the use of TE materials in AF applications. 711HPW/RH was tasked to test the efficacy of these TE materials for both electrical power generation and cooling garments. This study is a first step in determining the efficacy of TE materials to regulate an Airmen's core body temperature in hot environments using a TE vest prototype, Figure 1, and a solid state cooling device, Figure 2. The study was approved by the 711 HPW Institutional Review Board (IRB) under Protocol F-WR-2010-0086-H.

Figure 1. TE vest prototype

Figure 2. Solid state cooling device

1.2 TE Technology

Solid state cooling systems, or TE materials, consist of a semiconductor based bi-metal junction, a heat sink, and direct current (DC) power. A typical TE heating/cooling system is a sandwich-type structure of doped bismuth telluride (Bi_2Te_3) soldered between two ceramic plates. Bi_2Te_3 acts as a semiconductor and after doping, the material becomes an efficient TE. Variations in doping create P-N junctions throughout the TE. Figure 3 shows a schematic of a TE device and the alignment of the P-N junctions. A P-N junction is formed at the boundary between a P-type (positive) and N-type (negative) semiconductor. When current is passed through the junctions, a temperature differential is achieved to produce both a hot and cold side of the TE.

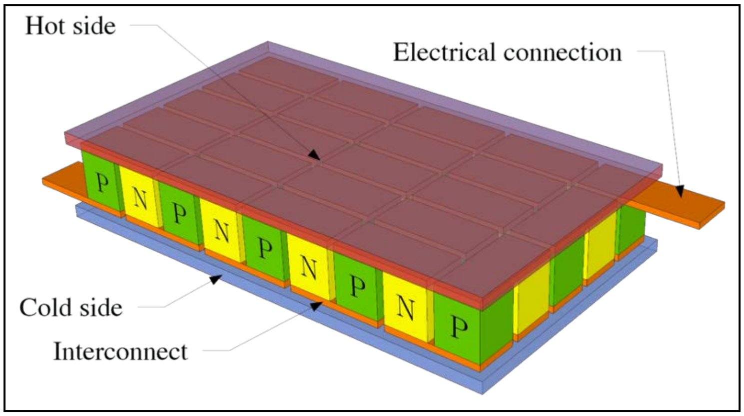

Figure 3. P-N junction elemental schematic

There are several advantages of using TE materials to heat and cool over conventional methods. Conventional refrigeration uses a compressor, condenser, evaporator, and refrigerants which together require large amounts of space and energy to operate. TE heating and cooling systems require no condensers, evaporators, or refrigerants and use about half the power to achieve the same cooling capacity as non-solid state systems. Additionally, TE heating/cooling systems have no moving parts, offering higher reliability and lower maintenance over other types of more conventional devices. TE heating/cooling systems also provide a very low noise signature compared to compressor style systems. Lastly, TE-based solid state cooling systems contain no chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), or hybrid fiber coaxial (HFC) types of refrigerants.

The TE cooling units used for this study were made by Marlow Industries in Dallas, TX. The TE units were constructed of two bismuth telluride TE. Aluminum fins were attached to the ceramic plates on both sides of the TEs to act as heat sinks. The units have three hot-side fans, one cold-side fan, and the casing is made from a 3D printer prototype acrylonitrile butadiene styrene (ABS) plastic material. Flow rate was measured at 20 cubic feet per minute (CFM) of airflow.

The Generation I prototype vests were fabricated by the AF Uniform Office at WPAFB, OH. They were constructed using channeled 3D spacer fabric encased with an outer layer of minimally air-permeable fabric. The fabric making up the inner lining of the vest is in a gradient

from less-to-more air permeable from the middle back (least air permeable) around the sides of the vest to the chest area (most air permeable), Figure 4. The air is forced from the TE cooling unit into the middle-lower back of the vest by way of a manifold piece constructed from the ABS plastic material. The gradation in fabric air permeability distributes cold air from the middle-lower back of the vest around the contours of the torso to the upper-front chest of the vest, Figures 5 and 6.

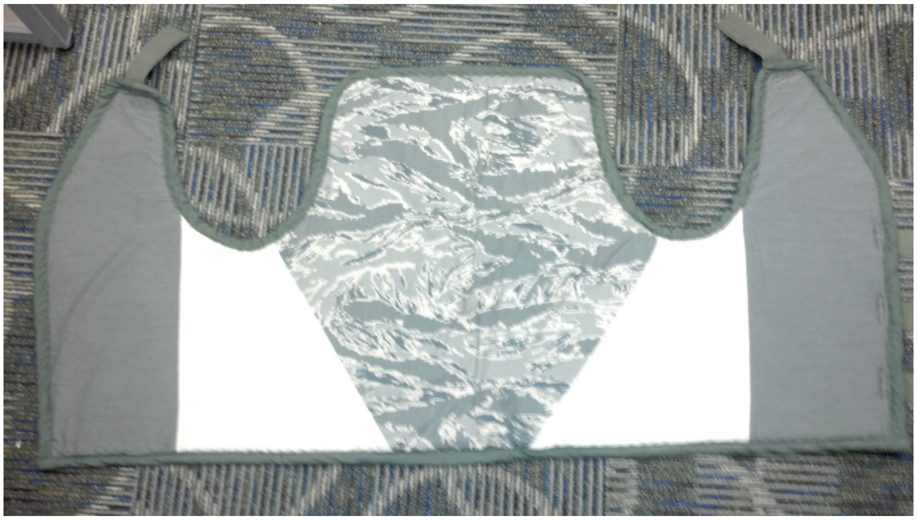

Figure 4. Inner lining of the vest

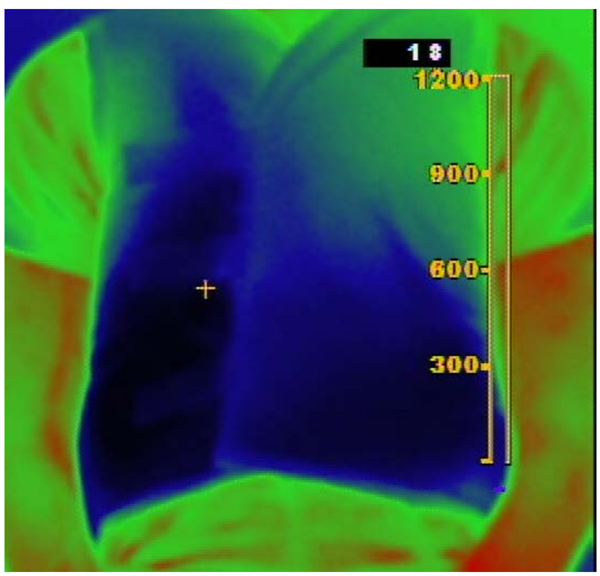

Figure 5. Thermal imaging showing vest front after 5 minutes (7.2° F drop)

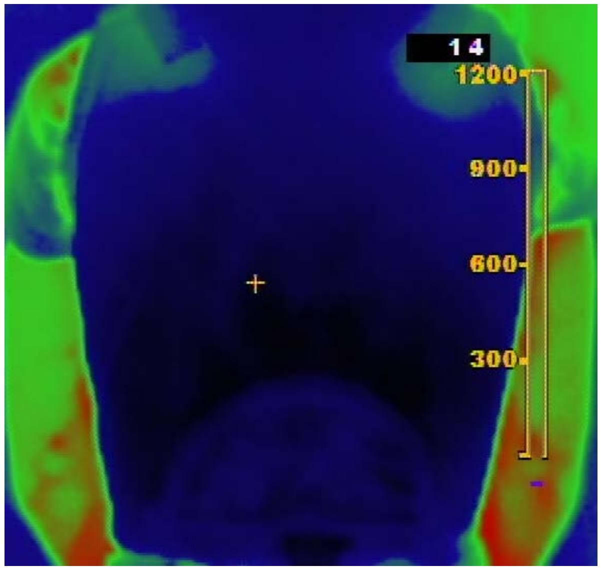

Figure 6. Thermal imaging showing vest back after 5 minutes (10.9° F drop)

2.0 METHOD

2.1 Summary of Technical Approach

A series of tests were completed using eleven subjects. An ergometer was used to raise core body temperature through physical exercise. A subject-specific submaximal test can be determined by running baseline maximal oxygen uptake (VO_{2max}) on each subject. VO_{2max} is accepted as the criterion measure of cardiorespiratory fitness. VO_{2max} is the product of the maximal cardiac output (L/min) and arterial-venous oxygen difference (mL O2/L). The two to three-fold difference in VO_{2max} (L/min) that exists across populations is due primarily to differences in maximal cardiac output; therefore, VO_{2max} is related to the functional capacity of the heart. Designing a subject-specific submaximal test with a vigilance task, each subject completed a total of four submaximal tests wearing the vest 'on' twice and 'off' twice to determine efficacy of the vest. From collected core body temperature and vigilance data, conclusions can be drawn about an effect of vest in general and vest over time (vest*time interaction).

2.2 Facilities and Equipment

All testing occurred at Wright-Patterson AFB in the 711th Human Performance Wing Human Performance Laboratory (HPL).

2.2.1 Ergonometer

A Lode B.V. Excalibur Sport Ergonometer was used to increase subject's core body temperature. The Excalibur Sport is a multi-adjustable ergonometer and is designed for heavy-duty sports physiology use. The physical workload is controlled electromagnetically and continuously adjustable up to 2500W. Due to the design, this ergometer is extremely stable during high loads.

Both pedaling speed dependent and independent ergometry are possible. The Excalibur Sport can be controlled by the ParvoMedics TrueOne 2400 metabolic cart.

2.2.2 Environmental Sensors

Relative humidity and temperature were measured using an Indoor Health Products Model 910 Humidity Sensor with specifications and function shown in Table 1 and Table 2, respectively.

Table 1. Sensor specifications

Humidity Measuring Ranges	20-99% RH (Relative Humidity)
Resolution	1%
Accuracy	+/- 3% RH
Measuring Period	Every 10 seconds

Table 2. Temperature measuring function

Humidity Measuring Ranges	-0°C to 50°C (32°F to 122°F)
Resolution	0.1°
Accuracy	+/- 1°C (+/- 2°F)
Measuring Period	Every 10 seconds

2.2.3 Metabolic Cart

A ParvoMedics TrueOne® 2400 was used during a VO_{2max} test to baseline subject exertion. The TrueOne® 2400 is a compact, integrated metabolic measurement system for indirect calorimetry and maximal O_2 consumption measurement. The O_2 analyzer paramagnetic range is either 0-100% or 0-25% with a 0.1% accuracy and response of less than 50ms. The CO_2 analyzer infrared range is 0-10% with 0.1% accuracy and a response of less than 90ms. Flow and volume measurements were taken with a Rudolph screen pneumotach having a range of 0-800 liters/minute and an accuracy of +/-2%. The ParvoMedics TrueOne 2400 metabolic cart can control the Excalibur Sport ergonometer.

2.2.4 Thermometer Pill

A CorTemp (HQ Inc, Palmetto, FL) Ingestible Core Body Thermometer Pill was used to measure core body temperature during testing. The system consists of a small silicon-coated pill containing a crystal quartz oscillator, which transmits a low-frequency radio wave to an external receiver/data logger worn by the subject. The frequency of the radio wave varies proportionally to the temperature of the pill (Mittal 1991, O'Brian 1998). The manufacturer calibrates each pill such that frequencies recoded by the data logger can be related to the temperature. Data recorded on the logger are downloaded to a computer after data collection for later analysis. The CorTemp system was used to record subject's core body temperature while using the cooling garments. The CorTemp system was successfully used in a minimal risk study at Brooks City Base (Balldin 2007), is currently in use by multiple college and professional football teams, and has been used by NASA during shuttle missions.

2.2.5 TE Material Prototype Vest and Solid State Cooling Device

The TE Prototype Vest and Solid State Cooling Device are described in section 1.2 'TE Technology'.

2.3 Subjects

Fourteen volunteer subjects were initially enrolled in this study. All subjects that volunteered reviewed the IRB approved protocol, signed ICDs, and were medically cleared by a medical doctor before testing. Only male subjects between 144 lbs and 220 lbs with a body height between 67 in. and 76 in. were used in accordance with ASTM Standard F2300-5. The subjects were active duty military members that passed USAF physical fitness standards and ranged in age between 23 and 41 years. The subjects' weights, heights, and ages are provided in Table 3. Tests were conducted during multiple sessions with a minimum of 72 hours between tests allowing the CorTemp pill to pass through the gastrointestinal system. Subjects 2, 5, and 7 did not complete testing and were removed from all analyses. The remaining 11 subjects completed all testing and were used for data analysis.

Subjects' activity, food, and fluid intake the day prior to each test was *ad libitum* with the exception of alcohol, which was prohibited. Subjects were asked to swallow a CorTemp ingestible pill six hours prior to the test with a small amount of water and food. Subjects refrained from eating within four hours and from drinking fluids within two hours prior to the test.

Table 3. Subject heights, weights, and ages

Subject ID Number	Weight [lbs]	Height [in]	Age [years]
1	152	68	24
2	155	69	24
3	161	67	24
4	195	73	24
5	150	67	24
6	181	69	23
7	175	69	28
8	187	73	24
9	178	70	38
10	218	72	31
11	202	76	23
12	174	72	25
13	177	71	26
14	172	68	41

2.4 Methodology

Prior to testing with the TE vest prototype, all subjects were tested to find their VO_{2max} while on the ergonometer. This test consisted of using the ergonometer as well as a metabolic cart to measure the oxygen (O_2) and carbon dioxide (CO_2) exhaust ratio (as seen in Figure 7). Figure 8 shows the outline of the physical task that was completed to determine their overall VO_{2max}. This test lasted until the subjects reached volitional fatigue and could not advance further in the task.

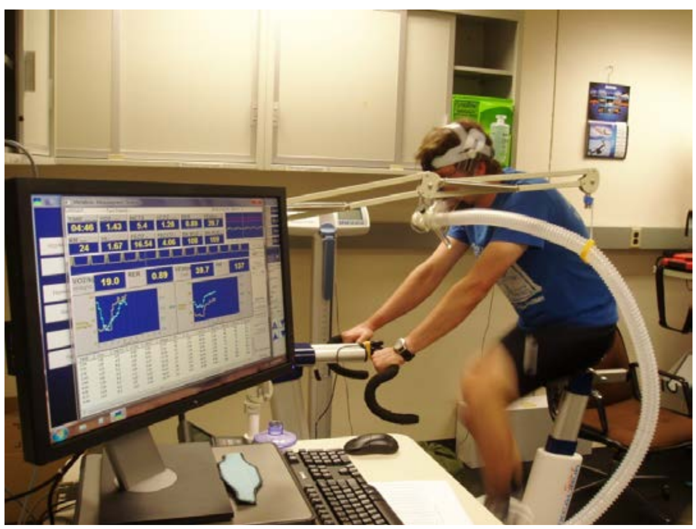

Figure 7. Stationary bike used for testing with the metabolic cart.

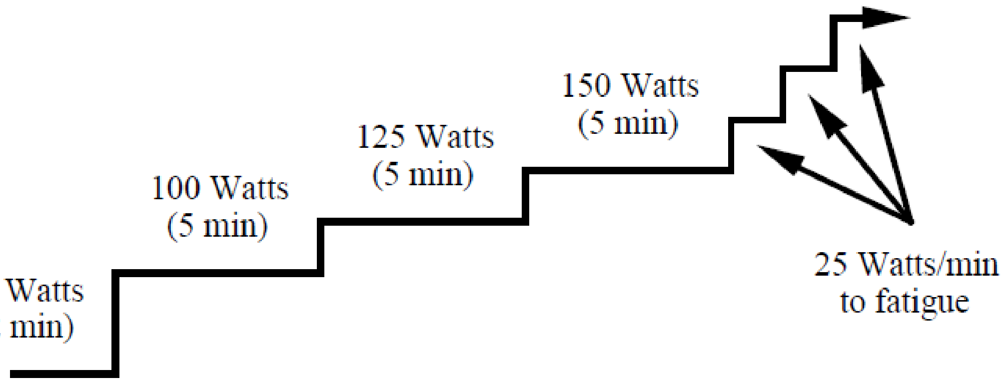

Figure 8. Baseline test to determine a subjects VO_{2max}

A subject-specific submaximal exercise protocol was established based on the maximum effort and VO_{2max} recorded. The submaximal test included four periods of activity; the subjects biked for 20 minutes with no resistance, biked 20 minutes at 40% of their VO_{2max}, biked 20 minutes at 65% of their VO_{2max}, and then rested for 20 minutes with no activity as shown in Figure 9 (VO_{2max} is the equivalent of VO_{2pk}). This 80-minute submaximal protocol was previously used by NASA to fit a submaximal test per subject (Fortney 1998).

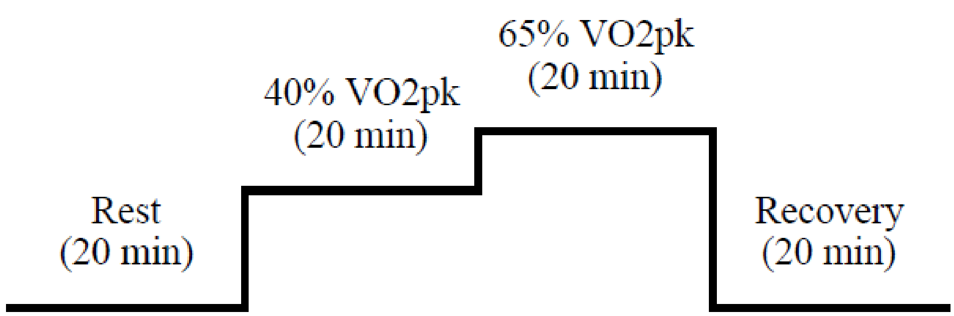

Figure 9. Submaximal test for individual subjects

The vigilance task used was an Air Traffic Controller task that consisted of a combination of flight paths that were either neutral or critical as shown in Figure 10. Neutral events are scenarios that do not simulate a crash event and provide no response from the subjects where a critical event does simulate a crash event and requires a response. Subjects identified critical events through clicking a mouse mounted to the handlebars of the ergonometer. The timing of critical events, neutral events, and responses were recorded. The task compiled the data by calculating whether the response was a Hit, Miss, or False Alarm and included the time at which the response occurred. These data were analyzed every 10 minutes (Nelson 2012). Hits and Misses weigh the same and were represented by a percentage of how many Hits were obtained

during each segment. This allows for a single percentage to represent an entire 10 minute segment. If any portion of the segment was not completed, the data could not be used due to the randomness of the task and potential misrepresentation of a segment.

Core body temperature was measured using the CorTemp system that was ingested six hours before initiating the submaximal test. Temperature was recorded every ten seconds during the test.

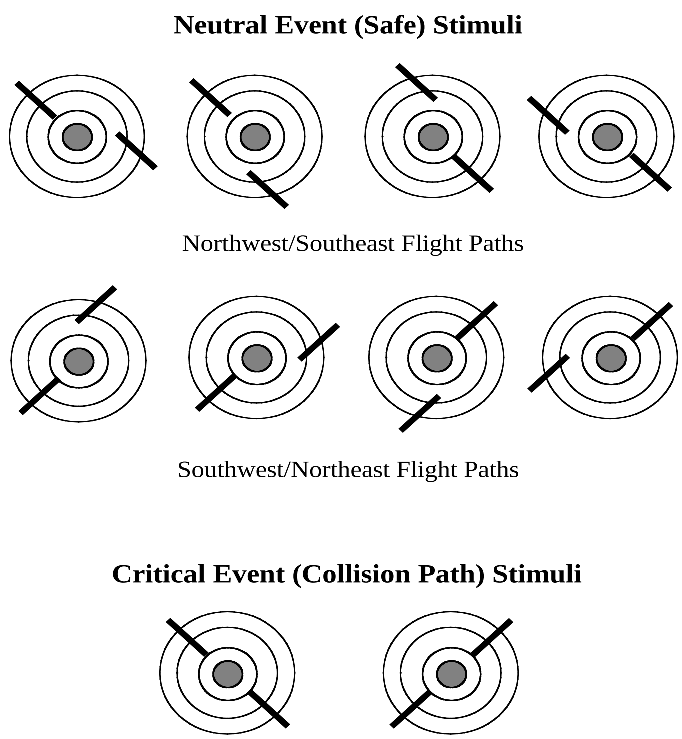

Figure 10. Vigilance task possible neutral and critical events

The subject wore the TE vest during the first 60 minutes of four separate 80-minute submaximal tests due to the last 20 minutes being a recovery stage. The vest was ‘on’ for two tests and ‘off’ for two tests. The order of vest off/vest on was counterbalanced across subjects in an ‘abba’ test matrix (on, off, off, on order or vice-versa). By using this design and averaging across days within a subject (for each vest condition), the order effect of day, learning, and changes in physical ability were to some degree minimized.

2.5 Procedures

2.5.1 Baseline Maximal O_2 Uptake Test

Subjects wore a heart rate monitor as well as a fitted mask for VO_{2max} testing with the metabolic cart. Each subject was tested according to the baseline test shown in Figure 8 and the metabolic cart calculated each subject's VO_{2max}.

The subject then performed a cool down physical task unrelated to their VO_{2max}. During cool down the subject practiced the vigilance cognitive task. A submaximal testing protocol was then established for each subject based on the results of the VO_{2max} baseline test.

2.5.2 Submaximal Test

Investigators met with each subject at least six hours prior to testing with the vest to ingest the CorTemp pill. The six hours ensured that the CorTemp pill was in the gastrointestinal track. The cognitive task and TE cooling unit were set up for each subject depending on the 'on' or 'off' test condition. If it was an 'on' test, the cooling unit was connected to the vest. The metabolic cart was used to run the submaximal testing protocol unique to each subject based on the VO_{2max} baseline test as shown in Figure 9. When the subject was ready, the CorTemp data collection, cognitive task, cooling unit (if an 'on' day), and metabolic cart were synchronized and started.

2.5.3 Data Collection

The core body temperature data was collected using a CorTemp Data Recorder every 10 seconds. This was then downloaded to a computer for analysis.

The vigilance task records the times a neutral or critical event is displayed as well as the responses from the subject. The responses were stored on the server from where the task was run. These responses were compiled and analyzed to determine if the subjects responses were either a hit, miss, false alarm, or neutral event (in the case that no response is needed and no response was recorded).

2.6 Statistical Analysis

The Mixed Procedure in Statistical Analysis System (SAS), version 9.2, was used to perform repeated measures analyses of variance. Vest, time, and the vest*time interaction were fixed effects while subject (n = 11) and all interactions with the subject were random effects. All F-tests used Satterthwaite-type degrees of freedom.

Post-hoc paired comparisons of time used the Bonferroni procedure with a 0.05 experiment-wise error level.

3.0 RESULTS

The main purpose of the analysis was to determine whether the cooling vest had an effect on core body temperature and percent hits during the vigilance task. Due to missing data, different sets of subjects were used in analyses of particular times.

3.1 Core Body Temperature

The core body temperature of each subject was recorded by the thermometer pill every ten seconds during the submaximal test. The temperatures within a full ten minute segment were averaged so that a single temperature could represent the entire 10 minute segment. If any of the cognitive data was missing for the time segment, then temperature data was not included in the data analysis for that time segment to mirror the cognitive data. Core body temperatures from each test were plotted against time for each subject in Figure 11.

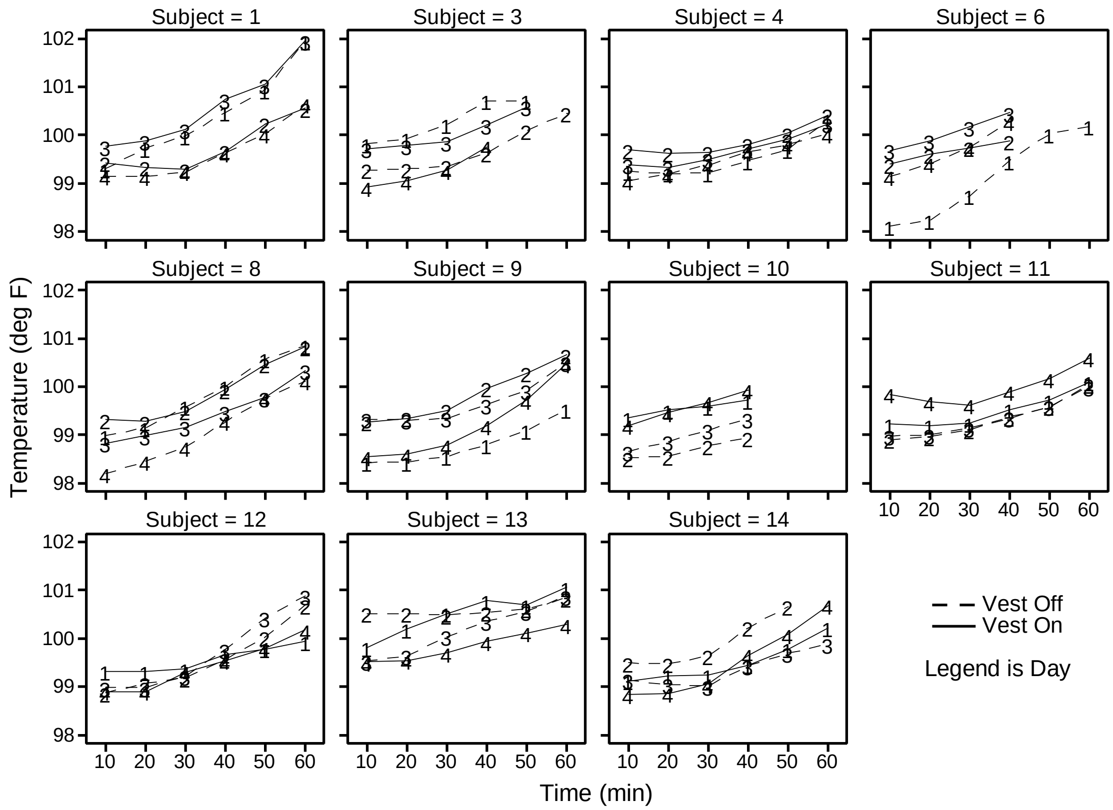

Figure 11. Mean temperatures for each subject using 10 minute segments

All subjects were able to complete up to the end of the 40 minute segment of their submaximal testing. Subjects 3, 6, 10, and 14 were unable to finish either one or all of their tests and have missing data. Due to the missing data, averaging of the temperature data could not be completed for every subject during the 10-60 minute intervals. The data that is averaged together are both 'off' days to form a new set and both 'on' days to form another set. Averaging with missing data would not accurately represent that specific segment containing the missing data. The approach taken was to average all data for the segments that contain data from 10-40 minutes for comparison and then to average all data for only subjects who completed the task. Mean and standard error (SEM) for the given set of subjects are shown in Table 4 and Figures 12 and 15.

Table 4. Mean and SEM on temperature for main effects and vest*time interaction

		Temperature (deg F)			
		11 Subjects		7 Subjects	
Vest	Time	Mean	SEM	Mean	SEM
Off		99.33	0.12	99.66	0.15
On		99.53	0.08	99.79	0.11
	10	99.20	0.09	99.22	0.13
	20	99.28	0.09	99.29	0.14
	30	99.45	0.09	99.44	0.14
	40	99.79	0.10	99.78	0.14
	50			100.09	0.13
	60			100.53	0.14
Off	10	99.07	0.13	99.10	0.17
	20	99.16	0.12	99.20	0.17
	30	99.35	0.12	99.37	0.17
	40	99.72	0.12	99.71	0.16
	50			100.04	0.16
	60			100.52	0.18
On	10	99.32	0.08	99.34	0.11
	20	99.39	0.09	99.37	0.12
	30	99.54	0.09	99.52	0.12
	40	99.86	0.08	99.85	0.12
	50			100.13	0.11
	60			100.54	0.14

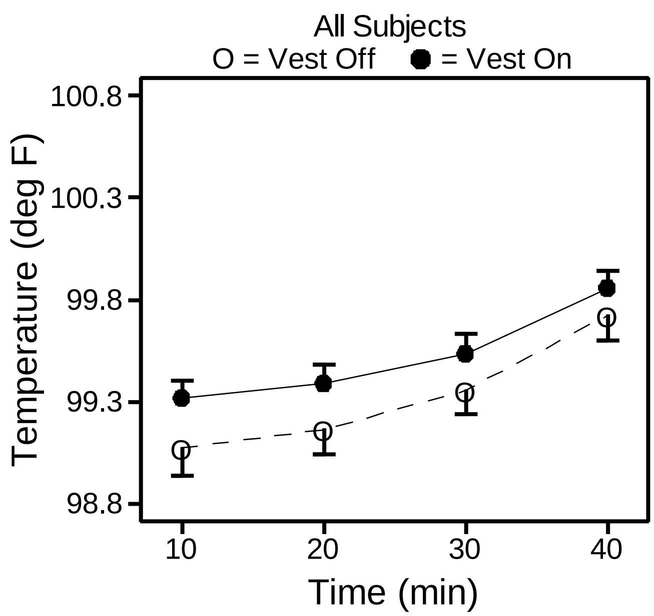

Figure 12. Mean (+ or - SEM) for temperatures of 11 subjects from 10-40 minutes

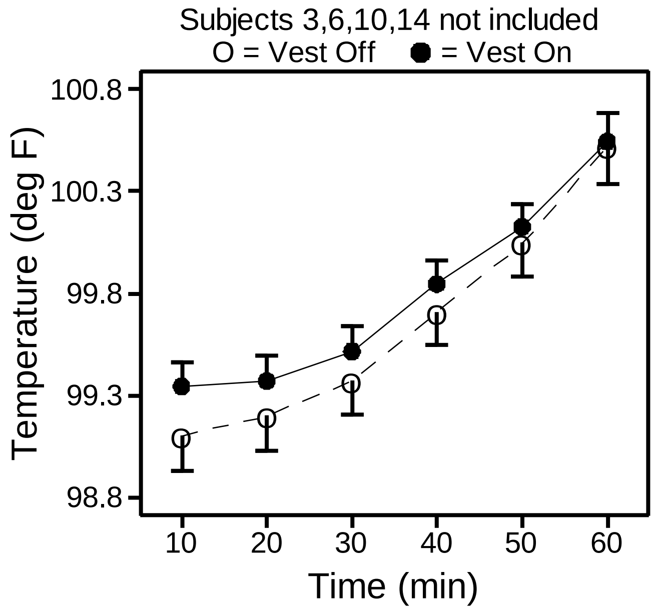

Figure 13. Mean (+ or - SEM) for temperatures of 7 subjects from 10-60 minutes

Table 5 tabulates the Analysis of Variance (ANOVA) model, showing degrees of freedom (DF), f-values, and p-values for the temperature with respect to vest, time, and vest*time interactions using all subject data averaged across days in Figure 11. The importance of the p-value shows if there was a significant difference in the effect or not with anything <0.05 being significant. Bonferroni post-hoc paired comparisons showed all pairs of times were significantly different from each other except for 10 minutes versus 20 minutes in both analyses, 10 minutes versus 30 minutes using 7 subjects, and 20 minutes versus 30 minutes using 7 subjects. This confirms that the core body temperature of the subjects increased over time for both the 'on' and 'off' vest conditions as they performed physical exercise. However, this analysis shows there was no statistical difference between the 'on' and 'off' vest configurations.

Table 5. ANOVA results for temperature

Dependent Variable	Effect	Times 10-40 minutes, 11 subjects				Times 10-60 minutes, 7 subjects			
		Num DF	Den DF	F	p	Num DF	Den DF	F	p
Temperature	Vest	1	10	3.80	0.0797	1	6	2.57	0.1598
	Time	3	30	89.94	0.0001	5	30	66.19	0.0001
	Vest*Time	3	30	1.47	0.2437	5	30	1.04	0.4141

3.2 Vigilance Performance

3.2.1 Hits

The percent Hits were plotted against time for each subject and are shown in Figure 14.

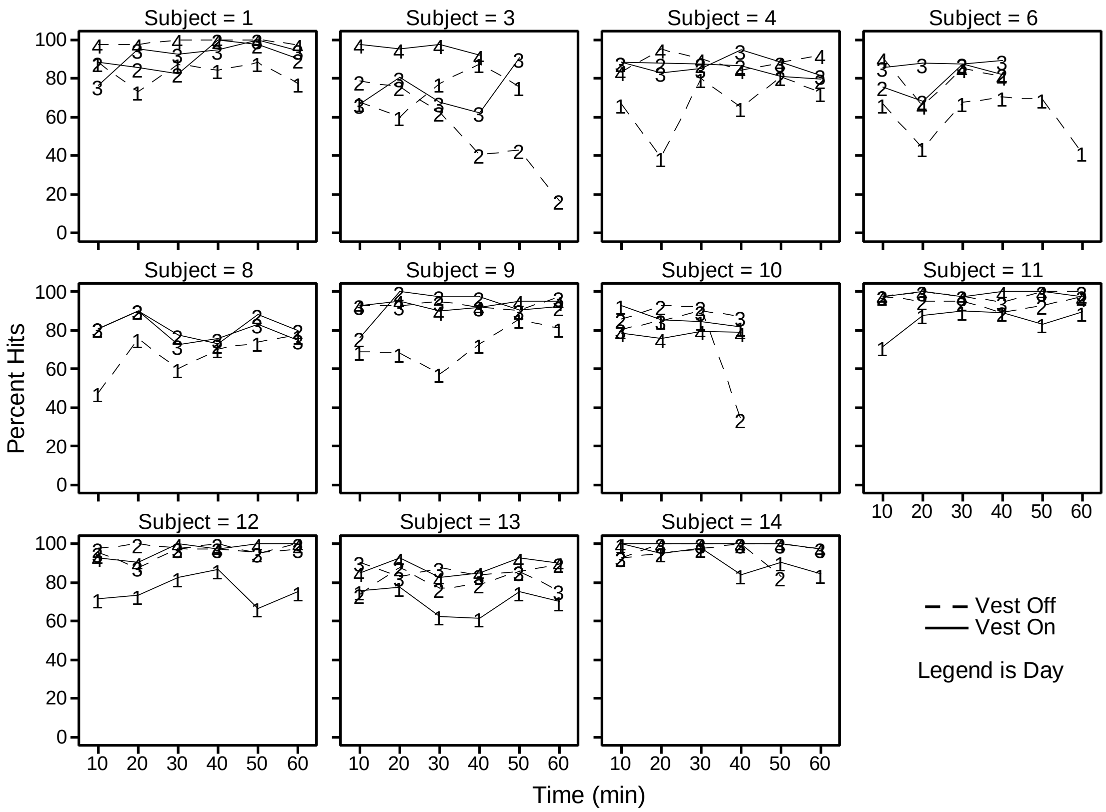

Figure 14. Mean percent hits for each subject using 10 minute segments

All subjects were able to complete up to the end of the 40 minute segment of their submaximal testing protocol. Subjects 3, 6, 10, and 14 were unable to finish either one or all of their tests and have missing data. The intervals chosen were the same as the temperature data. Mean and SEM for the given set of subjects is shown in Table 6 and Figures 15 and 16. Subject 8 vigilance task data was not included in the analysis because of data collection error during one of the submaximal tests. Since the 'abba' design could not be fully completed for Subject 8, averaging the 'on' and 'off' days would misrepresent the data.

Table 6. Mean and SEM on percent hits for main effects and vest*time interaction

			Percent Hits			
			10 Subjects		6 Subjects	
Vest	Time		Mean	SEM	Mean	SEM
Off			83.99	3.36	88.03	3.17
On			87.01	1.85	87.91	2.13
	10		85.13	1.84	85.56	1.74
	20		84.82	2.94	86.96	2.59
	30		87.13	2.38	87.98	2.73
	40		84.92	3.17	88.60	2.99
	50				89.91	1.97
	60				88.84	2.51
Off	10		85.24	2.83	87.49	3.82
	20		81.88	4.55	84.95	4.40
	30		86.69	3.23	88.47	3.51
	40		82.14	4.31	86.83	3.62
	50				90.65	2.11
	60				89.82	3.01
On	10		85.03	1.83	83.62	1.11
	20		87.77	2.19	88.96	2.46
	30		87.56	2.36	87.50	3.26
	40		87.70	2.61	90.36	3.55
	50				89.16	2.57
	60				87.87	2.57

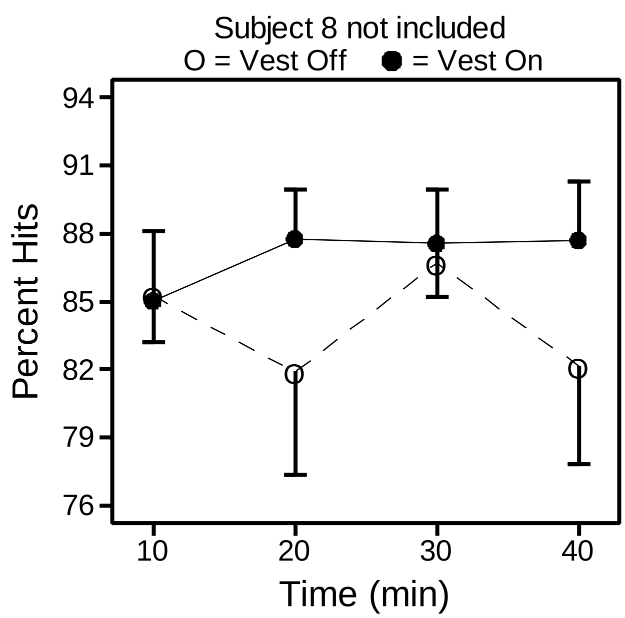

Figure 15. Mean (+ or - SEM) for percent hits of 10 subjects from 10-40 minutes

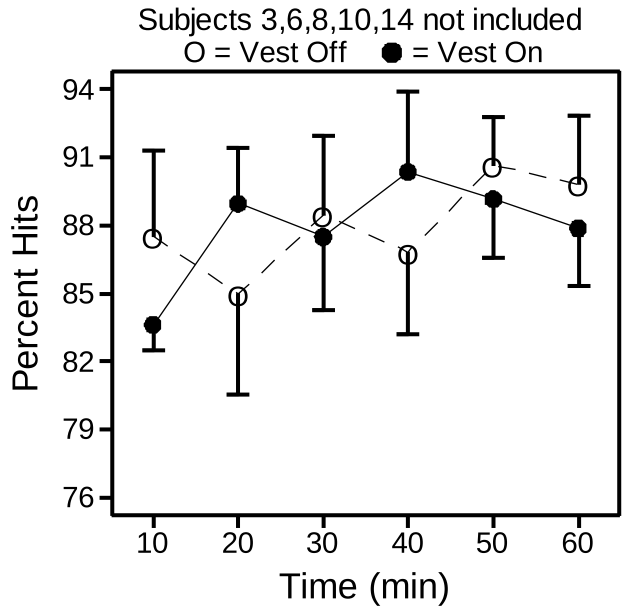

Figure 16. Mean (+ or - SEM) for percent hits of 6 subjects from 10-60 minutes

Table 7 shows the ANOVA model for the percent hits with respect to the vest, time, and vest*time interactions using the means in Figure 14. The same approach was taken for percent Hits as the temperature when determining the ANOVA table.

Table 7. ANOVA results for percent hits

Dependent Variable	Effect	Times 10-40, 10 subjects				Times 10-60, 6 subjects			
		Num DF	Den DF	F	p	Num DF	Den DF	F	p
Percent Hits	Vest	1	9	1.22	0.2988	1	5	0.01	0.9710
	Time	3	27	0.61	0.6130	5	25	1.53	0.2161
	Vest*Time	3	27	1.95	0.1461	5	25	1.86	0.1374

3.2.2 Misses

Misses is the inverse of Hits when graphed (Misses + Hits = 100%). Due to this the Miss data was not analyzed as it shows the same relationship.

3.2.3 False Alarms

False Alarms were analyzed every 10 minutes in the same method as percent Hits. False Alarms and Correct Rejections (CR) (or amount of neutral events that occurred) weigh the same and were represented by a percentage of how many False Alarms the subject obtained during each segment. This allowed for a single percentage to represent an entire 10 minute segment. If any portion of the segment was not completed, the data could not be used due to the randomness of the task and could misrepresent a segment. The percent False Alarms were plotted for each subject over time and is seen in Figure 17.

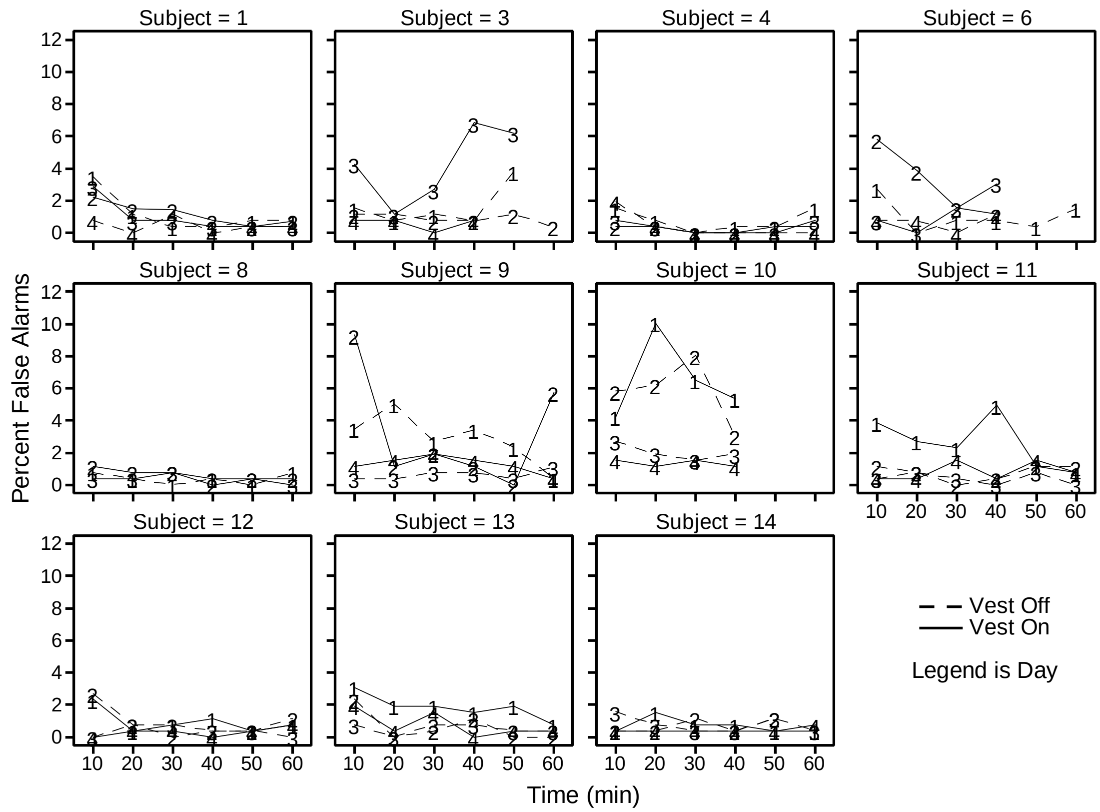

Figure 17. Mean percent false alarms for each subject using 10 minute segments

The data missing from False Alarms is the same data missing from Hits. The intervals chosen for analysis were the same as Hits (subjects from 10-40 minutes and subjects who completed from 10-60 minutes). This data was analyzed to calculate the means and SEMs for the given set of subjects as seen in Figures 18 and 19. Subject 8 was not included while calculating the overall mean percent Hits as there was an error in data collection during one of the submaximal tests. The desired percent False Alarms was <2% to ignore the effects of mis-clicking as a rule of thumb. If the overall percent false alarms was >2%, an extra analysis of determining overall truth of the subject through positive predictive power (PPP) would have been determined per individual subject. Given the overall average across all subject was <2%, the PPP was not calculated for each subject.

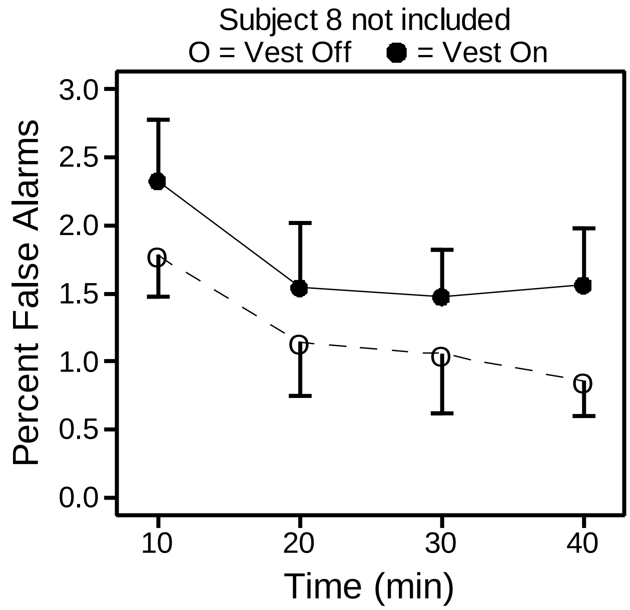

Figure 18. Mean (+ or - SEM) for percent false alarms of 10 subjects from 10-40 minutes

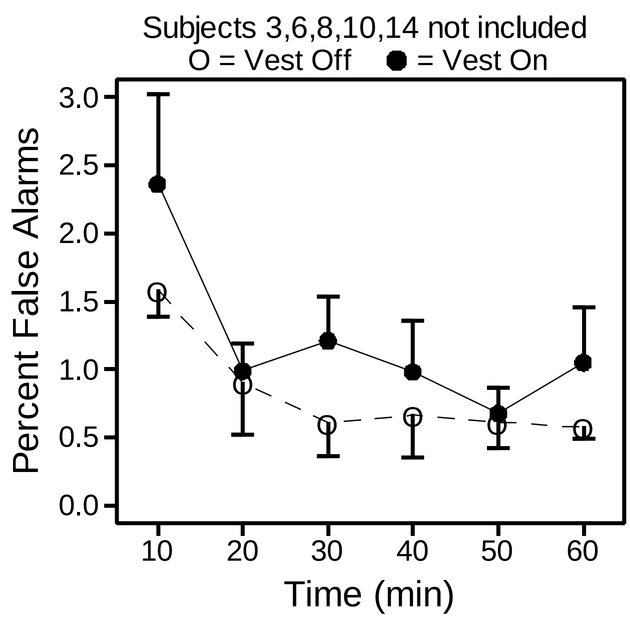

Figure 19. Mean (+ or - SEM) for percent false alarms of 6 subjects from 10-60 minutes

4.0 DISCUSSION

4.1 Core Body Temperature

There was a significant effect of time on the temperature ($p<=0.05$). This was expected as the subjects completed a physical exercise task on the ergonometer. The effect of the vest and the vest*time interaction found no significant effects.

The TE unit took approximately 20-30 minutes to start working efficiently, which is visible in both Figures 12 and 13. In both figures the temperatures for the 10-20 minute segments stay approximately the same distance apart with small SEMs. As the subject progresses to the 30-60 minute segments, it can be seen that the temperatures converge, showing that the vest had a small effect on core body temperature. This effect, although present, was found to not be statistically significant over time. This was seen for time segment 10-40 minutes for vest*time ($p=0.2437$) and vest ($p=0.2988$) and time segment 10-60 minutes for vest*time ($p=0.4141$) and vest ($p=0.1598$) as shown in Table 5.

The heat generated by the individual's body, given the conditions of the test environment, appeared to overcome any cooling the vest provided. This is seen in the 20-30 minutes the vest required to become efficient in providing cool air for the subject. It appeared that the lack of cooling from the TE unit could be seen as heating the subject initially more than it did to cool the subject. The heat produced by the subject's body would then become trapped in the space between the subject and the vest. This was seen in the vest 'on' configuration appearing to be higher in core body temperature than the 'off' configuration as seen in Figures 12 and 13, but the effect becomes smaller as the tests progressed.

4.2 Vigilance Performance

There was no statistical significance found in the vest, time, and vest*time interactions for percent Hits. This was seen for time segment 10-40 minutes for vest ($p=0.2988$), time ($p=0.6130$), and vest*time ($p= 0.1461$) and time segment 10-60 minutes for vest ($p=0.9710$), time ($p=0.2161$), and vest*time ($p=0.1374$) as seen in Table 7. In Figure 15 the percent Hits appeared to be significantly higher across the board with vest 'on', but the SEMs were large enough that there was no statistical significance found with respect to the data collected. In Figure 16, the vest 'on' configuration appeared to have almost no effect when compared to the 'off' configuration as the data crosses.

The False Alarms across all subjects was <=2% and were not accounted for in their individual PPP. This shows that the False Alarms were not statistically significant enough to play a role in the subjects' response and should not have been a determining factor in the analysis.

5.0 CONCLUSION

The prototype vest, with the specific test parameters and current design, had no significant positive effects on core body temperature cooling or increased cognitive vigilance. This is most likely due to the TE cooling unit generating more heat initially and the vest trapping the heat close to the subjects' body, the environment of the testing being relatively benign, or the physical task not significantly increasing core body temperature.

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SYMBOLS

°	Degree
%	Percent

ABBREVIATIONS

CFM	Cubic Feet per Minute
HPL	Human Performance Lab
STT	Strategic Technology Team
TE	Thermoelectric

ACRONYM

ABS	Acrylonitrile Butadiene Styrene
AFRL	Air Force Research Laboratory
ANOVA	Analysis of Variance

Bi_2Te_3	Bismuth Tellurium
CFC	Chlorofluorocarbon
CR	Correct Rejection
DC	Direct Current
DF	Degrees of Freedom
DoD	Department of Defense
HCFC	Hydrochlorofluorocarbon
HFC	Hybrid Fiber Coaxial
IRB	Institutional Review Board
PPP	Positive Predictive Power
SAS	Statistical Analysis System
SEM	Standard Error Mean
VO_{2max}	Maximal Oxygen Uptake (also seen as VO_{2pk})
WPAFB	Wright-Patterson Air Force Base
711HPW	711^{th} Human Performance Wing